50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO.

2.

3. Recipient's Accession No. PB85 218220/AS

4. Title and Subtitle
HURRICANES IWA, ALICIA, AND DIANA--COMMON THEMES, A Report of the Committee on Natural Disasters, 1984

5. Report Date 1985

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
National Research Council
Commission on Engineering and Technical Systems
2101 Constitution Avenue, N.W.
Washington, DC 20418

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G) NSF-8413362

12. Sponsoring Organization Name and Address
National Science Foundation
1800 G Street, N.W.
Washington DC 20550

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

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17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement:
Distribution unlimited

19. Security Class (This Report) Unclassified

20. Security Class (This Page)

21. No. of Pages 35

22. Price $8.50

(See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

PB85-218220

Hurricanes Iwa, Alicia, and Diana—Common Themes

A Report of the
Committee on Natural Disasters, 1984

Division of Geotechnical Engineering and Hazard Mitigation

Commission on Engineering and Technical Systems

National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1985

NOTICE: The Committee on Natural Disasters project, under which this report was prepared, was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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This study was supported by the Federal Emergency Management Agency, the National Oceanic and Atmospheric Administration, and the National Science Foundation under NSF Grant No. CEE-8219358 to the National Academy of Sciences. Any opinions, findings, and conclusions or recommendations expressed in this report are the committee's and do not necessarily reflect the views of the sponsoring agencies, the National Research Council, or the committee members' organizations.

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INTRODUCTION

The National Research Council has maintained the Committee on Natural Disasters--originally known as the Committee on Earthquake Inspection--since 1966. The goals of the committee are to collect perishable data on natural disasters while the data are still available, to provide conveniently available accounts of natural disasters, and to identify and recommend cases where more in-depth studies could improve engineering practice, preparedness, warning systems, public response, or recovery.

To meet these goals the committee has traditionally organized study teams to visit the sites of natural disasters, including earthquakes, tornadoes, landslides, a volcanic eruption, hurricanes, floods, and tsunamis, as soon after the event as possible. The study teams are charged with a variety of tasks, including collecting data on the nature and magnitude of the disaster-causing event, evaluating the effects of the disaster on buildings, lifelines, and other man-made structures and systems, assessing the preparedness and response of public agencies to the disaster, gauging the sociological impacts of the disaster, and describing steps to mitigate the effects of future disasters. The study teams are characterized by their ability to respond rapidly when a disaster occurs and by the broad, interdisciplinary mix of specialties and backgrounds represented on a typical team.

Since 1980 the committee has maintained a list of potential team members, specialists in a number of fields who have responded to a committee questionnaire indicating their availability and interest in serving on a postdisaster study team when an opportunity arises. These specialists have provided the committee with information on their specialties and subspecialties, language capabilities, and passport status. Since 1980, 22 of these specialists have responded to a committee request that they serve as a team member or team leader for a field study and prepare a postdisaster report. Appendix A is a list of the committee's approximately 200 potential team members as of December 31, 1984.

In addition to sending study teams into the field to investigate the effects of natural disasters, the committee has organized and participated in symposia held after natural disasters to collect, organize, and publish experience and data relating to the disaster. Appendix B lists the committee's reports of postdisaster studies and symposia completed through 1984.

From the committee's inception until July 1984 its work was supported solely by annual grants from the National Science Foundation. Beginning on August 1, 1984, two other federal agencies, the Federal Emergency Management

Agency and the National Oceanic and Atmospheric Administration of the Department of Commerce, joined with the National Science Foundation in providing financial support for the committee's activities.

At its annual meeting in November 1984 the committee decided that each year it should prepare a report presenting a generic analysis of one area of its work--postdisaster studies on earthquakes, hurricanes, tornadoes, floods, landslides, or volcanoes--as well as summarizing the committee's postdisaster study activities for the previous year. The report would be useful to committee members, potential team members, members of the Commission on Engineering and Technical Systems, and the committee's sponsors.

This is the committee's first report to present a generic analysis of several recent postdisaster studies--those of Hurricanes Iwa Alicia, and Diana. It also includes brief descriptions of the committee's other postdisaster study activities in 1984.

ACTIVITIES OF THE COMMITTEE ON NATURAL DISASTERS IN CALENDAR YEAR 1984

Five postdisaster study teams completed reports in 1984 from field studies made in 1983. Also, an overview report was completed for a conference held in August 1982 at Stanford University. After being reviewed by representatives of the Committee on Natural Disasters and the Commission on Engineering and Technical Systems, these reports were approved for publication, printed, and distributed to specialists in the United States and in 37 other countries. The field work for two other postdisaster studies was completed in 1984, and reports based on this work were being prepared at the end of the year.

TSUNAMI ON THE JAPANESE AND KOREAN COASTS

On May 26, 1983, a major earthquake in the central region of the Sea of Japan generated a moderate tsunami that struck the coasts of Japan and Korea. Li-San Hwang of Tetra Tech, Inc., in Pasadena, California, and Joseph Hammack of the University of Florida, Gainesville, investigated for the committee the tsunami and its effects.

Their report noted the development of three or four main waves in the tsunami with periods of about 10 minutes. Short-period waves also appeared on the main waves, which helped to dissipate the waves' energy before they struck the coasts. Both of these aspects of the tsunami warrant further investigation, as do the conditions under which bores form and migrate across the wave crest.

Approximately 100 people lost their lives in the tsunami, underscoring the importance of effective tsunami warning systems and public education about the dangers of tsunamis. Much of the damage from the tsunami was caused by floating structures colliding with other structures. If ships and other floating structures could be moved to offshore areas before a tsunami struck, much of this damage could be avoided.

The report was distributed in April 1984 to about 500 specialists in tsunami analysis and research and to federal, state, and local agencies concerned with preparedness for, warning of, and response to coastal flooding.

CALIFORNIA COASTAL EROSION

During the winter of 1982-83 the coast of California was battered by waves that were the most severe of the century. The resulting erosion and structural damage caused losses of several hundred million dollars. Robert G. Dean, University of Florida, Gainesville; George A. Armstrong, Department of Boating and Waterways, State of California, Sacramento; and Nicholas Sitar, University of California, Berkeley, conducted a reconnaissance survey for the committee of the coast from the Mexico-California border to Stimson Beach.

Their report described the damage to coastal and offshore structures, the processes that contributed to the damage, and the effectiveness of stabilization and protective measures such as revetments and seawalls. It stressed the importance for coastal development planners of understanding the natural and man-made processes that change the shoreline. The report enumerated specific areas requiring additional research to understand shoreline erosion, including the role of waves, winds, and tides in accelerating erosion, the influence of offshore bars, the roles of land subsidence and sea level rises, and the stabilization of coastal cliffs.

The team's report was reviewed and completed in the summer of 1984. It was distributed in the fall to about 1,300 specialists in coastal flooding and erosion.

UTAH LANDSLIDES, DEBRIS FLOWS, AND FLOODS

Snowpacks in the watersheds of Utah were 150 to 400 percent above normal in the spring of 1983. After a period of below-normal temperatures, above-normal temperatures in late May generated widespread flooding and landsliding. Twenty-two of Utah's twenty-nine counties were included in a national disaster area.

Loren R. Anderson, Utah State University, Logan; Jeffrey R. Keaton, Dames & Moore Consulting Engineers, Salt Lake City; Thomas F. Saarinen, University of Arizona, Tucson; and Wade G. Wells, U.S. Forest Service, Riverside, California studied and reported on this disaster. The professions represented by the team were, respectively, geotechnical engineering, geology, the social sciences, and hydrology.

The report described the geology and meteorological and hydrological conditions that combined to produce the disaster. It then described the flooding, landsliding, and debris flows that occurred during the period and analyzed selected events in detail. Following a description of the human impact of the events, it listed the many excellent research opportunities afforded by the disaster to enhance the understanding of landslides and debris flows.

The report was distributed in September 1984 to 1,100 specialists in landsliding, debris flows, flooding, and preparedness, mostly in the western United States.

HURRICANE ALICIA

Hurricane Alicia came ashore near Galveston, Texas, and crossed over the Houston area during the morning of August 18, 1983. Though not a strong hurricane, Alicia affected a densely populated modern metropolitan area, causing extensive wind and flooding damage. Rudolph P. Savage, Offshore & Coastal Technologies, Inc., Fairfax, Virginia; Jay Baker, Florida State University, Tallahassee; Joseph H. Golden, National Oceanic and Atmospheric

Administration, Silver Spring, Maryland; Ahsan Kareem, University of Houston; and Billy R. Manning, Southern Building Code Congress International, Birmingham, Alabama, studied the hurricane and the damage it caused.

Their report investigated five major aspects of the storm: the meteorology, the storm surge and shore processes, the damage to buildings and structures, the damage to lifelines, and the warnings about, responses to, and recovery from the storm. For a summary of the report's major findings, refer to Chapter 3, "Common Themes from Recent Hurricane Reports."

The report was distributed in August 1984 to about 2,000 hurricane and preparedness specialists.

TUCSON, ARIZONA, FLOOD

A tropical weather pattern caused extensive flooding in southern Arizona in late September and early October 1983. A four-man team consisting of Thomas F. Saarinen, University of Arizona, Tucson; Victor R. Baker, University of Arizona, Tucson; Robert Durrenberger, Scottsdale, Arizona; and Thomas Maddock, Jr., Tucson, reported on the flooding that occurred at a specific place and time--Tucson, Arizona, on Sunday, October 2, and Monday, October 3.

The Tucson metropolitan area provided an interesting locale for the study for two reasons. The first was that it offered an example of the ways in which floods of desert streams differ from floods in humid areas. On desert valley floors, true floodplains with overbank flows are rare while lateral erosion of arroyo banks is common, and floodplain zoning that assumes other conditions may be inappropriate. The second reason was that the experience in Tucson has implications for other metropolitan areas in desert regions that are undergoing rapid growth.

The report was completed and distributed to about 1,?00 flooding and preparedness specialists in November 1984.

TORNADOES IN SOUTH CAROLINA

A major storm moved northeasterly across South Carolina and North Carolina during the afternoon and evening of March 28, 1984, generating 21 separate tornadoes that killed 57 people, injured 1,300, and left 3,000 homeless. The committee's resources for field studies were exhausted at the time, so a full postdisaster study team could not be dispatched to document the effects of the tornadoes. However, the committee invited from the list of potential team members a specialist in the effects of wind on structures, Peter R. Sparks, Clemson University, to make a preliminary survey of the performance of engineered structures in Bennettsville, South Carolina, and nearby communities and advise the committee of his findings.

The survey included observations of the performance of single-family homes, mobile homes, multiple-unit dwellings, and public buildings in Newberry, Winnsboro, and Bennettsville, South Carolina. Sparks and his colleagues at Clemson University also conducted an analysis and wind tunnel study of a severely damaged hybrid steel and masonry shopping center in Bennettsville, one that was designed in an area where the Standard Building Code has been adopted.

The report of the field study, including the results of the shopping center analysis and wind tunnel study, will be completed and distributed in the first part of 1985.

HURRICANE DIANA

Hurricane Diana looped off the coast of North Carolina for almost 36 hours and then came ashore near Wilmington, North Carolina, early in the morning of September 13, 1984. It provided an excellent opportunity for studying the effects of, and responses to, a moderately sized hurricane.

A team consisting of social scientist James K. Mitchell, Rutgers University, New Brunswick, New Jersey; lifelines specialist Ahmed M. Abdel-Ghaffer, Princeton University; meteorologist R. Cecil Gentry, Clemson University; coastal storms specialist Stephen P. Leatherman, University of Maryland, College Park; and structural engineer Peter R. Sparks, Clemson University, was dispatched by the committee to study the event. Chapter 3, "Common Themes from Recent Hurricane Reports," includes some of the findings from a preliminary version of their report. The final report will be completed and distributed about mid-1985.

SAN FRANCISCO BAY REGION DEBRIS FLOWS, LANDSLIDES, AND FLOODS

In early January 1982 as much as 25 inches of rain fell in the coastal mountains of the San Francisco Bay region in a period of 32 hours. This storm triggered hundreds of debris flows and landslides and produced floods in many areas. Damage to homes, businesses, highways, bridges, and communication facilities exceeded a quarter billion dollars. Thirty-three people lost their lives.

Social scientist Thomas F. Saarinen, University of Arizona; planner Martha Blair, Wm. Spangle Associates, Portola Valley, California; and geotechnical engineer Nicholas Sitar, University of California, Berkeley, were invited to represent the Committee on Natural Disasters in organizing the conference and preparing an overview report. Their chapters in the overview examine specific topics discussed at the conference, while a summary section prepared by William Brown III of the U.S. Geological Survey distills the discussions and findings of the more than 400 disaster specialists and public officials who attended the conference.

Among the conclusions of these contributors are the following: the communities of the region were not prepared for the storm; there was no local flood warning system, although such a system was feasible and in use in other parts of the country; local governments have permitted development in areas where there exist abundant data describing geologic and hydrologic hazards; and although there is considerable information on slope stability hazards in the area, little information on the specific hazard of debris flows was available prior to the storm. A summary report of the conference papers and discussions was prepared jointly by the committee and the Branch of Engineering Geology and Tectonics of the U.S. Geological Survey. The report was completed and distributed to about 700 flood, landslide, and debris flow specialists in April 1984.

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COMMON THEMES FROM RECENT HURRICANE REPORTS

Since 1982 the Committee on Natural Disasters has dispatched study teams to gather information for three reports dealing with hurricanes that have affected the United States: Hurricane Iwa, which struck the Hawaiian islands of Niihau, Kauai, and Oahu on November 23, 1982; Hurricane Alicia, which struck the Galveston-Houston, Texas, area on September 17-18, 1983; and Hurricane Diana, which struck the North Carolina coast on September 11-13, 1984.

None of these hurricanes was particularly intense. Iwa did not produce a single case of sustained hurricane-force winds at observational stations on Oahu or Kauai, and no significant wind speed records were broken. At landfall Alicia was a medium-sized hurricane of only slightly greater than average intensity. Diana, though a category 3 storm on the Saffir-Simpson scale on September 11, was only a weak category 1 storm when it finally came ashore on September 13.

Yet each of these hurricanes caused substantial damage, and together they demonstrate the great vulnerability of today's coastal populations to more serious hurricane disasters. Iwa was the most costly natural disaster ever to affect the Hawaiian Islands, with damage estimates in excess of $200 million. A similar storm, Hurricane Dot, which struck the islands in 1959, caused only $5.7 million in damage. Hurricane Alicia was the third most costly storm to strike the United States in recent decades, with damage estimates of from $750 million to $1.65 billion. Even the relatively mild Hurricane Diana caused damages estimated at $80 million.

The predominant factor contributing to the expense of recent hurricanes is the extensive coastal development that has occurred in the areas affected (Figure 1). Many shoreline areas in the United States have become increasingly built up and populated over the past few decades, heightening the potential for threats to life and property in the event of a hurricane. At the same time, continuing development of the coastline has created or exacerbated problems for meteorologists, geoscientists, engineers, and emergency planners who must anticipate and prepare for coastal storms. This chapter draws on the three recent hurricane reports of the Committee on Natural Disasters to highlight those problems and to specify areas where additional work is needed.

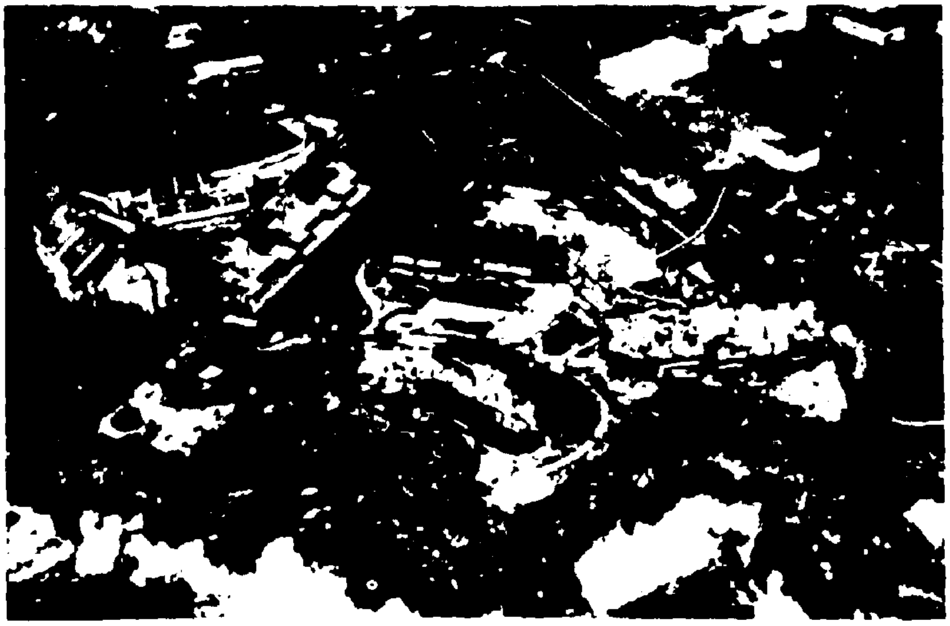

FIGURE 1 Extensive development along shorelines susceptible to hurricanes has greatly increased the potential for property damage and loss of life. This photograph shows a condominium development on the island of Kauai after the passage of Hurricane Iwa.

METEOROLOGY

All three hurricanes had unusual meteorological features that complicated the task of forecasting their development. Iwa formed exceedingly late in the year and approached the northernmost Hawaiian Islands from an unusual direction, the southwest. Alicia recurved rather sharply to the right, executed some cycloidal looping motions, and strengthened rapidly in the hours before landfall. Diana stalled off the shore of North Carolina for nearly 36 hours, gradually losing strength as its center described a slow clockwise loop over the ocean.

For both Alicia and Diana the environmental "steering winds" around the hurricanes, which forecasters often use to predict hurricane tracks, were very weak. This affected the forecasts issued for the two storms in different ways. For Alicia the National Weather Service's statistical-climatological models outperformed its dynamical models in predicting the storm's track, though all of the models predicted a landfall to the left of where it actually occurred. For Diana the reverse held true, and the dynamical models were superior in predicting the storm's movements.

Alicia was the first hurricane for which the National Weather Service publicly used a new probability system that gives the likelihood of a storm passing within 65 miles of various coastal locations. Although the information was occasionally misinterpreted by the media, it does not seem to have caused undue confusion among the population. By the same token, the probability information issued for Diana did not lead to any significant early evacuations of the forewarned populace.

With coastal development continuing to increase, better techniques for predicting a hurricane's track and intensity are vital, though there has been slow progress. The lead times now needed to safely evacuate many coastal areas with limited road access--such as Galveston Island's 26 hours--dangerously exceed current forecasting capabilities. There is also a need to fill in the serious gaps that still exist in the meteorological networks near coasts susceptible to hurricanes.

The study teams for all three hurricanes had difficulty obtaining reliable wind speeds for the storms. Their recommendations included standardizing anemometer heights to provide for common comparisons, providing backup power and automatic recording capabilities for all meteorological instruments that can provide information about severe storms, and hastening the deployment of the Next Generation Radar (NEXRAD) system, a Doppler radar network being developed jointly by the Departments of Defense, Commerce, and Transportation.

COASTAL PROCESSES

Nine out of ten deaths caused by hurricanes are the result of flooding, as the storm surge, waves, tides, and in some cases rainfall send water coursing onto normally dry land. Flooding was a factor in each of the three hurricanes investigated by the Committee on Natural Disasters, though it varied in severity.

After the passage of Hurricane Iwa the debris line on the developed, southerly shore of Kauai extended up to 300 yd inland of the 100-year flood boundary determined by the Federal Emergency Management Agency in a flood insurance study of the area (Figure 2). This 100-year flood elevation was in general 6 to 14 ft above mean sea level. Clearly, these flood levels need to be reestablished to consider the effects of tropical and extratropical storm surge with wave action, as well as the effects of tsunamis. Also, structures near the shoreline need to be protected, since it is unlikely that commercial property owners will consider a retreat from oceanfront sites.

In Hurricane Alicia, maximum water levels in front of Galveston Island may have been as much as 12 ft above mean sea level. However, the Galveston seawall and the practice of elevating structures reduced the loss of life and damage to property to a fraction of what they could have been. The lower parts of western Galveston Island were overtopped. In some cases the flooding appears to have initiated structural damage that was then intensified by wind forces. The storm surge also drove water into the complex of bays behind Galveston and Follets islands, and this water later flowed back into the Gulf, cutting channels through the dunes of the barrier islands. Native grasses on the islands were surprisingly effective in preventing scour and erosion in all areas apparently unaffected by significant wave action.

In Hurricane Diana the maximum storm surge was probably only about 5-1/2 ft, and it arrived on a falling tide. Still, some parts of the town of Carolina Beach were flooded, and erosion on some beaches was substantial. Two houses already threatened by erosion were damaged or destroyed. But the coastal erosion was no greater than what would be expected from a severe winter storm.

FIGURE 2 Flooding on the island of Kauai during Hurricane Iwa extended up to 300 yd inland of the 100-year flood boundary set by the Federal Emergency Management Agency. This photograph shows damage to the interior of a hotel unit on Kauai caused by storm surge, waves, and flooding.

One of the major constraints on developing a better understanding of coastal processes is the lack of quantitative data from severe oceanic or coastal storms. One way to acquire this data would be to develop simple, inexpensive, portable, and sturdy wave/tide gauges that could be set up along coastlines before a hurricane or other storm came ashore. The information from such gauges could be used to calibrate the output from numerical models and to refine frequency-magnitude relationships for long-term forecasts.

STRUCTURES

The maximum wind speeds for all three hurricanes either did not exceed or were only slightly above the design wind speeds prescribed by applicable building codes. Yet Iwa and Alicia produced extensive wind damage, raising questions about the understanding of the effects of windstorms on structures, the adequacy of the building codes, and the extent of the codes' enforcement.

On Kauai, one in eight homes and about three fifths of the hotel units were damaged or destroyed by Iwa. Although the long duration and topographic channeling of the wind were factors in causing this damage, much of it appeared to be due to either poor design, inadequate provisions in the building code, or poor construction practices. Timber-framed structures were more susceptible to damage than were reinforced concrete and masonry shear wall structures, and most of this damage could be traced to inadequate fastening of the roof covering, poor anchorage of the roof systems to the walls, and weak connections of the stud walls to their foundations (Figure 3). A particular hazard to life and property was lightweight roof coverings, such as light gage metal sheeting, not adequately fastened to the purlins or beams (Figure 4). As windborne debris during the storm, these roof coverings caused considerable property damage and posed a hazard to life. These problems could be substantially eliminated by specific construction practices.

Along the beaches of Galveston Island nearly half of the buildings were severely damaged by Alicia's winds. Cladding damage due to inadequate fastenings accounted for the highest percentage of the total damage. In Houston the storm smashed hundreds of windows in a cluster of downtown high-rise office buildings (Figure 5), and it blew down parts of buildings, signs, and trees in other parts of the city and the surrounding area. Windborne debris was also a major problem in this storm, especially with regard to the window damage in downtown Houston, where debris from adjacent roofs and broken glass produced a chain reaction effect of broken windows. In general, provision of adequate fastenings and anchorage for houses in Galveston and preventive control of the availability of windborne debris, both large and small, in the downtown Houston area would have substantially reduced the damage caused by Alicia.

In North Carolina the situation was somewhat different. There many coastal jurisdictions comply with a stringent building code developed after a series of devastating hurricanes hit the area in the 1950s. Buildings designed to this code generally performed well. Most of the serious structural damage occurred to buildings predating the code, to buildings that had violated the code, or to buildings not subject to the code (such as those in South Carolina).

The three hurricanes demonstrated that the most important threats to structures are inadequate fastenings and anchorage and windborne debris. Also, codes designed to regulate these potential threats must be enforced to be effective. Diana revealed that many of the losses in a moderate hurricane come from widespread small-scale damage rather than from catastrophic failures. The damage from Iwa revealed that understanding of the effects of topographic features needs to be improved.

LIFELINES

The most severe damage to lifelines caused by the three hurricanes was to overhead power lines, telephone cables, and the poles on which they are suspended (Figure 6). In Iwa, wood poles failed and guy anchors pulled out, with power lost to the entire island of Kauai and 25 to 40 percent of the island's 18,000 telephone subscribers without service the day after the storm. During Alicia, about 60 percent of the electric customers in the area were without power, and approximately 20 percent of the telephone service in the Houston-Texas City-Galveston area was lost during and after the hurricane. In Diana, about 95 percent of Brunswick County was without power when the hurricane made landfall on September 13.

The loss of electricity also meant the loss of other lifelines services

FIGURE 3 A typical example of poor connections between subsystems, in this case on Galveston Island after the passage of Hurricane Alicia.

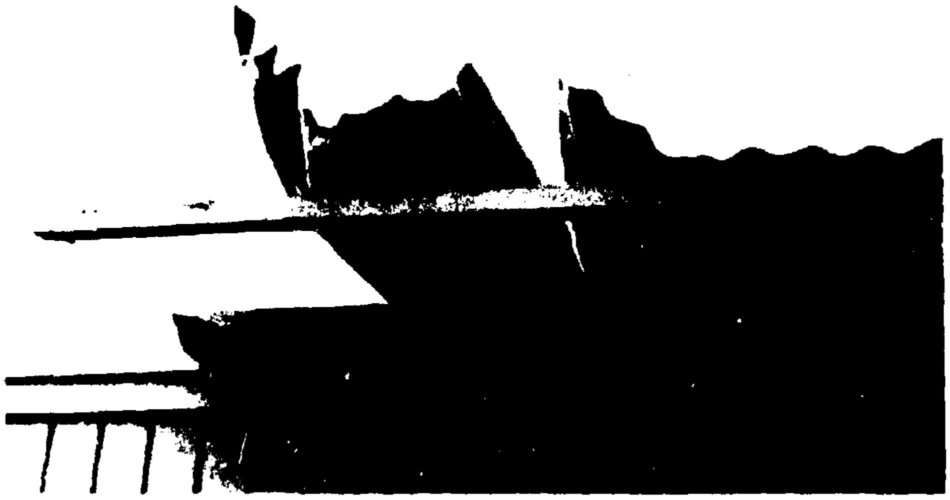

FIGURE 4 Light-gage corrugated metal sheeting used for a roof covering, as on this single-family dwelling in Kauai, can become airborne during hurricanes and cause considerable property damage, as well as posing a hazard to life.

FIGURE 5 Hundreds of windows in Houston's central business district were broken during Hurricane Alicia, as seen in this view looking west.

dependent on electricity. Water shortages occurred in all three areas after the hurricanes due to loss of power to electric pumps. The lack of refrigeration both increased the need for meals cooked by volunteer groups and made it more difficult for those groups to meet that need. The media were affected by downed antennas and loss of power; in the area affected by Diana, only one radio station managed to stay on the air.

To protect electric lines from the effects of hurricanes, some combination of the following steps could be taken, though none alone might be cost-effective. Lifelines could be buried or designed to withstand hurricane-force winds (one of the lessons from Diana concerned the advantages of burying power lines subject to such storms). Utilities could ensure that trees and shrubs along rights of way of distribution systems are kept trimmed. And all important lifeline services could be provided with backup power.

One unexpectedly pressing problem that arose in the aftermath of the storms was the amount of debris that had to be removed from roadways and other areas. An estimated 2 million cubic yards of debris was scattered across the Houston area after the storm, and cleanup costs were expected to be some $10 million.

RESPONSE AND RECOVERY

All three hurricanes revealed certain strengths and weakness in the emergency and evacuation plans in effect in each area. During Iwa there was considerable confusion about the status of the warnings and evacuation plans for Oahu,

FIGURE 6 The most severe damage to lifelines from hurricanes generally results from the downing of poles carrying power and telephone lines. This photograph shows a pole in Kauai that toppled during Hurricane Iwa due to failure of its soil embedment.

since a hurricane warning was never issued for that island. On Galveston Island, although most of the western part of the island and Bolivar Peninsula were evacuated before Alicia struck, the City of Galveston was not evacuated, possibly because of concern over what some people considered an "unnecessary" evacuation before Hurricane Allen three years before. In North Carolina, after an extremely successful initial evacuation, many people returned to their homes while the storm stalled offshore, and some of these people could not be reevacuated when the storm finally made landfall. However, in each of the three hurricanes the loss of life was much less than it would have been had the evacuations been less successful and timely.

None of the three areas had conducted a thorough survey of buildings that would be safe from wind and water forces during a hurricane. Such surveys should also take into account the evacuation procedures for an area. If an evacuation can only be partially completed, structures in the affected area should be identified as shelters for the people who remain behind.

4

THE FUTURE

The committee will continue to respond as opportunities arise, organizing study teams in situations where information useful to natural disaster researchers and practitioners can be obtained, interpreted, and reported. For each field study a summary of preliminary findings will be prepared, as soon after completion of the field work as possible, for distribution to committee members, potential team members, and sponsors. Reports of the studies will be prepared and distributed to the above and to other relevant parties as appropriate.

APPENDIX A:

COMMITTEE ON NATURAL DISASTERS POTENTIAL TEAM MEMBERS, 1984

EARTHQUAKES

Structures

Ahmed M. Abdel-Ghaffar	Princeton University
James E.Amrhein	Masonry Institute of America
Christopher Arnold	Building Systems Development
Robert G. Bea	PMB Systems Engineering
James E. Beavers	Union Carbide Corp.
James L. Beck	California Institute of Technology
James M. Becker	The Beacon Companies
Jacobo Bielak	Carnegie-Mellon University
Russell H. Brown	Clemson University
Arthur N. L. Chiu	University of Hawaii at Manoa
Jack Christiansen	Consultant, Seattle
W. Gene Corley	Portland Cement Assoc.
Marvin E. Criswell	Colorado State University
Eric Elsesser	Forell/Elsesser Engineers
Luis E. Escalante	LA Dept. of Water & Power
Anthony E. Fiorato	Division of Portland Cement Assoc.
John W. Foss, P.E.	Bell Laboratories
Douglas A. Foutch	University of Illinois at U-C
Peter Gergely	Cornell University
Subhash C. Goel	The University of Michigan
Robert D. Hanson	The University of Michigan
Gary C. Hart	Englekirk & Hart
Neil M. Hawkins	University of Washington
Keith D. Hjelmstad	Naval Civil Engineering Laboratory
Roy A. Imbsen	Engineering Computer Corp.
Jeremy Isenberg	Weidlinger Assoc.
James O. Jirsa	University of Texas
Lawrence F. Kahn	Georgia Institute of Technology
Ahsan Kareem	University of Houston
Eduardo Kausel	Massachusetts Institute of Technology
W. O. Keightley	Montana State University
Leon Kempner, Jr.	Bonneville Power Administration
Earl W. Kennett	The American Institute of Architects

Anne Kiremidjian	Stanford University
Armen Der Kiureghian	University of California
Richard Klingner	The University of Texas at Austin
Uwe F. Koehler	Ball State University
Helmut Krawinkler	Stanford University
H. S. Lew	National Bureau of Standards
Edgar V. Leyendecker	National Bureau of Standards
John Loss	University of Maryland
Le-Wu Lu	Lehigh University
Rene W. Luft	Simpson, Gumpertz, & Heger
Stephen Alan Mahin	University of California
Billy R. Manning	Southern Building Code Congress Intl.
Richard K. Miller	University of Southern California
Jack P. Moehle	University of California
Peter Mueller	Lehigh University
Vincent Murphy	Weston Geophysical
C. Dean Norman	USAE Waterways Experiment Station
H. Scott Norville	Texas A&M University
Michael O'Rourke	Rensselaer Polytechnic Institute
Joseph Penzien	University of California
Max L. Porter, P.E.	Iowa State University
Charles Scawthorn	Dames & Moore
Charles F. Scribner	University of Illinois
Larry Selna	University of California
H. C. Shah	Stanford University
Robin Shepherd	University of California
Peter Sparks	Clemson University
W. Pennington Vann	Texas Tech University
Marcy Wang	University of California
Yi-Kwei Wen	Naval Civil Engineering Laboratory
James K. Wight	The University of Michigan
Kyle A. Woodward	National Bureau of Standards
Loring A. Wyllie, Jr.	H. J. Degenkolb Assoc.
James T.P. Yao	Purdue University

Dams

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Keith G. Barrett	California Dept. of Water Resources
Jacobo Bielak	Carnegie-Mellon University
Gillis Bureau	Dames & Moore
Anil K. Chopra	University of California
John T. Christian	Stone & Webster Engineering Corp.
G. W. Clough	Virginia Polytechnic Institute
Lloyd S. Cluff	Woodward-Clyde Assoc.
W. Gene Corley	Portland Cement Assoc.
Pedro A. DeAlba	University of New Hampshire
Neville Clevely Donovan	Dames & Moore
Gordon W. Dukleth	Consultant, Carmichael, California
Joseph L. Ehasz	EBASCO Services, Inc.

James Erwin	Corps of Eng., S. Atlantic Div.
James V. Hamel	Hamel Geotechnical Consultants
Sergius N. Hanson	U.S. Bureau of Reclamation
George F. Horowitz	The Metro Water District of S. Calif.
Peter J. Hradilek	U.S. Bureau of Reclamation
I. M. Idriss	Woodward-Clyde Consultants
Walter E. Jaworski	Northeastern University
William R. Judd	Purdue University
Richard W. Kramer	U.S. Bureau of Reclamation
Ellis L. Krinitzsky	Waterways Experiment Station
G.A. Leonards	Purdue University
C. Eric Lindvall	Lindvall, Richter & Assoc.
Andrew H. Merritt	Andrew H. Merritt, Inc.
Vincent Murphy	Weston Geophysical
C. Dean Norman	USAE Waterways Experiment Station
Alan L. O'Neill	Converse Ward Dixon
Michael O'Rourke	Rensselaer Polytechnic Institute
Harry B. Seed	University of California at Berkeley
F. Thomas Turcotte	Woodward Clyde Assoc.
Robert V. Whitman	Massachusetts Institute of Technology
M. K. Yegian	Northeastern University
Chang-Hua Yeh	Harza Engineering Company

Architecture

James E. Amrhein	Masonry Institute of America
Christopher Arnold	Building Systems Development
Jack Christiansen	Consultant, Seattle
Richard K. Eisner	Bay Area Earthquake Study
Luis E. Escalante	LA Dept. of Water & Power
Earl W. Kennett	The American Institute of Architects
Uwe F. Koehler	Ball State University
Alcira Kreimer	The George Washington University
John Loss	University of Maryland
Billy R. Manning	Southern Building Code Congress Intl.
Satwant S. Rihal	California Polytechnic Institute
Peter Sparks	Clemson University
Marcy Wang	University of California

Lifelines

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Luis E. Escalante	LA Dept. of Water & Power
John W. Foss, P.E.	Bell Laboratories

Robert D. Hanson	The University of Michigan
Roy A. Imbsen	Engineering Computer Corp.
Jeremy Isenberg	Weidlinger Assoc.
Armen Der Kiureghian	University of California
Stephen Alan Mahin	University of California
Billy R. Manning	Southern Building Code Congress Intl.
James R. Morgan	Texas A&M University
Michael O'Rourke	Rensselaer Polytechnic Institute
Charles Scawthorn	Dames & Moore
Anshel J. Schiff	Purdue University
Larry Selna	University of California
H. C. Shah	Stanford University
Stuart D. Werner	Agbabian Assoc.

Geotechnical

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James E. Beavers	Union Carbide Corp.
James L. Beck	California Institute of Technology
Gillis Bureau	Dames & Moore
Gonzalo Castro	Geotechnical Engineers, Inc.
Anil K. Chopra	University of California
John T. Christian	Stone & Webster Engineering Corp.
G. W. Clough	Virginia Polytechnic Institute
Lloyd S. Cluff	Woodward-Clyde Assoc.
C. B. Crouse	Earth Technology Corporation
Art Darrow	Dames & Moore
Pedro A. DeAlba	University of New Hampshire
Neville Clevely Donovan	Dames & Moore
Bruce M. Douglas	University of Nevada, Reno
Herbert H. Einstein	Massachusetts Institute of Technology
James Erwin	Corps of Eng., S. Atlantic Division
Luis E. Escalante	LA Dept. of Water & Power
John W. Foss, P.E.	Bell Laboratories
Douglas A. Foutch	University of Illinois
Richard E. Goodman	University of California
James V. Hamel	Hamel Geotechnical Consultants
Gary C. Hart	Englekirk & Hart
I. M. Idriss	Woodward-Clyde Consultants
Roy A. Imbsen	Engineering Computer Corp.
Walter E. Jaworski	Northeastern University
William R. Judd	Purdue University
Ahsan Kareem	University of Houston
Eduardo Kausel	Massachusetts Institute of Technology
Anne Kiremidjian	Stanford University
Armen Der Kiureghian	University of California
Richard Klingner	The University of Texas at Austin
Uwe F. Koehler	Ball State University

John F. Kolars	University of Michigan
Ellis L. Krinitzsky	USAE Waterways Experiment Station
Stephen P. Leatherman	University of Maryland
G. A. Leonards	Purdue University
C. Eric Lindvall	Lindvall, Richter & Assoc.
Rene W. Luft	Simpson, Gumpertz, & Heger
Billy R. Manning	Southern Building Code Congress Intl.
Andrew H. Merritt	Andrew H. Merritt, Inc.
Jack P. Moehle	University of California
Vincent Murphy	Weston Geophysical
C. Dean Norman	USAE Waterways Experiment Station
Allen L. O'Neill	Converse Ward Dixon
Joseph Penzien	University of California
Anshel J. Schiff	Purdue University
H. C. Shah	Stanford University
Peter Sparks	Clemson University
Ta-liang Teng	University of Southern California
Stuart D. Werner	Agbabian Assoc.
Robert V. Whitman	Massachusetts Institute of Technology
M. K. Yegian	Northeastern University
T. Leslie Youd	Brigham Young University

Social Sciences

Jay Baker	Florida State University
Frederick L. Bates	University of Georgia
Jack Christiansen	Consultant, Seattle
John P. Clark	University of Minnesota
Russell R. Dynes	University of Delaware
Keith D. Hjelmstad	Naval Civil Engineering Laboratory
Walter E. Jaworski	Northeastern University
Douglas L. Johnson	Clark University
Robert W. Kates	Clark University
Leon Kempner, Jr.	Bonneville Power Administration
Thomas S. Kilijanek	Omni Research and Training
Uwe F. Koehler	Ball State University
John F. Kolars	University of Michigan
Alcira Kreimer	The George Washington University
Stephen P. Leatherman	University of Maryland
H. J. McPherson	University of Alberta, Canada
Dennis S. Mileti	Colorado State University
James R. Morgan	Texas A&M University
Joanne M. Nigg	Arizona State University
H. Scott Norville	Texas A&M University
Richard S. Olson	Arizona State University
Claire B. Rubin	George Washington University
Charles Scawthorn	Dames & Moore
Charles F. Scribner	University of Illinois
H. C. Shah	Stanford University
John Sorensen	Oak Ridge National Lab

Yi-Kwei Wen	Naval Civil Engineering Laboratory
Dennis Wenger	University of Delaware
James T.P. Yao	Purdue University

WINDSTORMS

Structures

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Celso S. Barrientos	Nat. Oceanic & Atmospheric Admin.
W. Lynn Beason	Texas A&M University
James E. Beavers	Union Carbide Corp.
Alfred J. Bedard, Jr.	Nat. Oceanic & Atmospheric Admin.
Arthur N. L. Chiu	University of Hawaii at Manoa
Jack Christiansen	Consultant, Seattle
W. Gene Corley	Portland Cement Assoc.
Marvin E. Criswell	Colorado State University
Frank H. Durgin	Massachusetts Institute of Technology
Anthony E. Fiorato	Division of Portland Cement Assoc.
John W. Foss, P.E.	Bell Laboratories
Douglas A. Foutch	University of Illinois at U-C
Raymond R. Fox	George Washington University
John C. Freeman	Institute for Storm Research
Gary C. Hart	Englekirk & Hart
Ahsan Kareem	University of Houston
Leon Kempner, Jr.	Bonneville Power Administration
Earl W. Kennett	The American Institute of Architects
Uwe F. Koehler	Ball State University
Alcira Kreimer	The George Washington University
H. S. Lew	National Bureau of Standards
Henry Liu	University of Missouri-Columbia
John Loss	University of Maryland
Stephen Alan Mahin	University of California
Billy R. Manning	Southern Building Code Congress Intl.
James R. McDonald	Texas Tech University
Kishor C. Mehta	Texas Tech University
Joseph E. Minor	Texas Tech University
James R. Morgan	Texas A&M University
C. Dean Norman	USAE Waterways Experiment Station
H. Scott Norville	Texas A&M University
Michael O'Rourke	Rensselaer Polytechnic Institute
Dale C. Perry	University of Idaho
Jon A. Peterka	Colorado State University
Richard E. Peterson	Texas Tech University
Max L. Porter, P.E.	Iowa State University
Dorothy A. Reed	University of Washington
Timothy A. Reinhold	National Bureau of Standards
Herbert S. Saffir, P.E.	Saffir, Consulting Engineers
Robert H. Simpson, PhD, CCM	Consultant, College Park, Maryland
Peter Sparks	Clemson University

Gerald M. Sullivan	Consulting Eng., Springfield, Tenn.
W. Pennington Vann	Texas Tech University
Yi-Kwei Wen	Naval Civil Engineering Laboratory
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Engineering Meteorology

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Gregory S. Forbes	Penn State University
John C. Freeman	Institute for Storm Research
R. Cecil Gentry	Clemson University
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Jill F. Hasling	Consultant, Houston
Leon Kempner, Jr.	Bonneville Power Administration
Edwin Kessler	National Severe Storms Laboratory
Griffith Morgan	Nat. Center for Atmospheric Research
Edward W. Pearl	Consultant, Lakewood, Colorado
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R. R. Rogers	McGill University
Frederick Sanders	Massachusetts Institute of Technology
Roger M. Wakimoto	University of California, Los Angeles
Ken Wilk	National Severe Storms Laboratory
Edward J. Zipser	Nat. Center for Atmospheric Research
Fred L. Zuckerberg	National Weather Service

Social Sciences

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Jay Baker	Florida State University
Frederick L. Bates	University of Georgia
Duane D. Baumann	Southern Illinois University
Robert Bolin	New Mexico State University
Jack Christiansen	Consultant, Seattle
John P. Clark	University of Minnesota
Thomas E. Drabek	University of Denver
Russell R. Dynes	University of Delaware
Robert W. Kates	Clark University
Leon Kempner, Jr.	Bonneville Power Administration
Uwe F. Koehler	Ball State University
Alcira Kreimer	The George Washington University
Joseph E.Minor	Texas Tech University
J. Kenneth Mitchell	Rutgers University
James R. Morgan	Texas A&M University
Brian Murton	University of Hawaii
H. Scott Norville	Texas A&M University
Edward W. Pearl	Consultant, Lakewood, Colorado
Yi-Kwei Wen	Naval Civil Engineering Laboratory

Dennis Wenger	University of Delaware
James T.P. Yao	Purdue University

FLOODS

Structures

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John T. Christian	Stone & Webster Engineering Corp.
Gordon W. Dukleth	Consultant, Carmichael, Calif.
Raymond R. Fox	George Washington University
Alfred S. Harrison	Corps of Eng., Missouri Division
Earl W. Kennett	The American Institute of Architects
Uwe F. Koehler	Ball State University
John Loss	University of Maryland
Billy R. Manning	Southern Building Code Congress Intl.
Joseph E. Minor	Texas Tech University
Nicholas Sitar	University of California, Berkeley
Ben Chie Yen	University of Illinois

Engineering Meteorology

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John C. Freeman	Institute for Storm Research
David H. George	Nat. Oceanic & Atmospheric Admin.
Jill F. Hasling	Consultant, Houston
Edwin Kessler	National Severe Storms Laboratory
Edward W. Pearl	Consultant, Lakewood, Colorado
R. R. Rogers	McGill University
Frederick Sanders	Massachusetts Institute of Technology
Ken Wilk	National Severe Storms Laboratory
Edward J. Zipser	Nat. Center for Atmospheric Research
Fred L. Zuckerberg	National Weather Service

Hydraulics/Hydrology

Harry H. Barnes	Meridian, Mississippi
Curtis B. Barrett	Nat. Oceanic & Atmospheric Admin.
B. J. Claborn	Texas Tech University
Alfred S. Harrison	Corps of Engineers, Missouri
Stephen P. Leatherman	University of Maryland
Carl F. Nordin, Jr.	U.S. Geologic Survey
Eugene L. Peck	HYDEX
Edward J. Zipser	Nat. Center for Atmospheric Research
Ben Chie Yen	University of Illinois

Coastal Engineering

Celso S. Barrientos	Nat. Oceanic & Atmospheric Admin.
Robert G. Dean	University of Florida
John C. Freeman	Institute for Storm Research
Andrew W. Garcia	USAE Waterways Experiment Station
Stephen P. Leatherman	University of Maryland
David B. Prior	Coastal Studies, Louisiana State
Rudolph P. Savage	U.S. Army, Fort Belvoir
Todd Walton	USAE Waterways Experiment Station

Social Sciences

Jay Baker	Florida State University
Duane D. Baumann	Southern Illinois University
Robert Bolin	New Mexico State University
John P. Clark	University of Minnesota
Thomas E. Drabek	University of Denver
Russell R. Dynes	University of Delaware
Robert W. Kates	Clark University
Uwe F. Koehler	Ball State University
Alcira Kreimer	The George Washington University
Stephen P. Leatherman	University of Maryland
Ian R. Manners	University of Texas
H. J. McPherson	University of Alberta, Canada
Dennis S. Mileti	Colorado State University
Joseph E. Minor	Texas Tech University
J. Kenneth Mitchell	Rutgers University
Edward W. Pearl	Consultant, Lakewood, Colorado
Ronald W. Perry	Arizona State University
Rutherford H. Platt	University of Massachusetts
Claire B. Rubin	George Washington University
Robert P. Walonsky	University of Wisc., Stevens Point
Richard A. Warrick	Nat. Center for Atmospheric Research
Marvin Waterstone	San Diego State University
Dennis Wenger	University of Delaware

LANDSLIDES

Amr S. Azzouz	Massachusetts Institute of Technology
Gregory B. Baecher	Massachusetts Institute of Technology
Leslie G. Bromwell	Bromwell Engineering, Inc.
Gillis Bureau	Dames & Moore
John T. Christian	Stone & Webster Engineering Corp.
G. W. Clough	Virginia Polytechnic Institute
Lloyd S. Cluff	Woodward-Clyde Assoc.
Pedro A. DeAlba	University of New Hampshire

Herbert H. Einstein	Massachusetts Institute of Technology
Raymond R. Fox	George Washington University
Richard E. Goodman	University of California, Berkeley
Walter E. Jaworski	Northeastern University
Uwe F. Koehler	Ball State University
Ellis L. Krinitzsky	USAE Waterways Experiment Station
T. William Lambe	Consultant, Longboat Key, Florida
G. A. Leonards	Purdue University
Andrew H. Merritt	Andrew H. Merritt, Inc.
Vincent Murphy	Weston Geophysical
David Prior	Louisiana State University
Nicholas Sitar	University of California, Berkeley
Ta-Liang Teng	University of Southern California
Barry Voight	Pennsylvania State University
Robert V. Whitman	Massachusetts Institute of Technology
M. K. Yegian	Northeastern University

VOLCANOES

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Art Darrow	Dames & Moore
Russell R. Dynes	University of Delaware
Herbert H. Einstein	Massachusetts Institute of Technology
Richard E. Goodman	University of California
Alfred S. Harrison	Corps of Engineers, Missouri
Neil M. Hawkins	University of Washington
Robert W. Kates	Clark University
Thomas S. Kilijanek	Omni Research and Training
Brian Murton	University of Hawaii
Ronald W. Perry	Arizona State University
John Sorensen	Oak Ridge National Laboratory
Ta-liang Teng	University of Southern California
Barry Voight	Pennsylvania State University
Richard A. Warrick	Nat.Center for Atmospheric Research

APPENDIX B:

NATIONAL RESEARCH COUNCIL REPORTS OF POSTDISASTER STUDIES, 1964-1984

Copies available from sources given in footnotes a, b, and c.

EARTHQUAKES

The Great Alaska Earthquake of 1964:[a]

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- Engineering, 0-309-01606-1/1973, 1198 pp.
- Geology, 0-309-01601-0/1971, 834 pp.
- Human Ecology, 0-309-01607-X/1970, 510 pp.
- Hydrology, 0-309-01603-7/1968, 446 pp.
- Oceanography and Coastal Engineering, 0-309-01605-3/1972, 556 pp.
- Seismology and Geodesy, 0-309-01602-9/1972, 598 pp., PB 212 981.[a,c]
- Summary and Recommendations, 0-309-01608-8/1973, 291 pp.

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The Western Sicily Earthquake of 1968 (1969) by J. Eugene Haas and Robert S. Ayre, 70 pp., PB 188 475.[c]

The Gediz, Turkey, Earthquake of 1970 (1970) by Joseph Penzien and Robert D. Hanson, 88 pp., PB 193 919.[b,c]

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[a] National Academy Press, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

[b] Committee on Natural Disasters, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

[c] National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

Destructive Earthquakes in Burdur and Bingol, Turkey, May 1971 (1975) by W. O. Keightley, 89 pp., PB 82 224 007 (A05).[b,c]

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LANDSLIDES

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HURRICANES

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